Ocean Model Development for COAMPS

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LONG-TERM GOALS

Develop a coupled ocean-atmosphere prediction system that can be used for hindcasting and forecasting coastal environments. This system is referred to as the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). The atmospheric component of this system was developed by the Atmospheric Dynamics and Prediction Branch of the Naval Research Laboratory (NRL) and is currently in use at NRL and at the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) (Hodur, 1997).

OBJECTIVES

The objectives of this project are to develop an ocean model that contains some of the best features of existing coastal ocean models, meets the Navy's needs for conducting simulations and predictions in littoral environments, and is scalable on multi-processor computers in common use by the Navy, to validate the performance of the model, and to fully couple the model with the atmospheric model within the current COAMPS program architecture.

APPROACH

COAMPS consists of coupled ocean and atmospheric models. Two ocean models have previously been used with COAMPS. The first of these models was developed by NRL for use in deep water and does not incorporate variable bottom depth. The other is the Modular Ocean Model (MOM) developed by the Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton. MOM has some limitations for coastal use, and the MOM code is not presently in a form that allows use of the full flexibility for which the COAMPS program architecture was designed.

For coastal applications, an ocean model is needed that can accommodate the wide range of environments and processes that can be encountered in coastal regions, including complex coastlines and bathymetry, tides and storm surge, river outflows and coastal runoff, and flooding and drying. The purpose of this project is to develop an ocean model to provide these capabilities. The ocean model being developed in this project is referred to as the Navy Coastal Ocean Model (NCOM).

Based on results from the Coastal Model Comparison study conducted by the NOMP Ocean Model Performance and Evaluation Project at NRL (Martin, et al., 1998), it was proposed that the ocean model to be developed for COAMPS consist of the following main elements: (a) the basic physics and numerics of the widely used Princeton Ocean Model (POM), (b) the combined sigma/z-level vertical grid system used in NRL's Sigma/Z-level Model (SZM), (c) a program structure fully consistent with COAMPS, and (d) some additional capabilities and refinements.

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A combined sigma/z-level grid system provides some additional flexibility over a sigma coordinate or a z-level system in setting up a vertical grid for a particular region. With the combined grid system, sigma coordinates are used down to a user-specified depth, and z-levels are used below. The z-level grid, which is generally more robust in regions of steep bottom slopes than sigma coordinates, can be applied at the depths below which steep bathymetry may cause difficulty with sigma coordinates. The combined grid system also allows comparisons to be made between sigma and z-level coordinates for a particular domain to identify problems that may be occurring with either coordinate system.

COAMPS has a very specific code architecture that is mainly defined by two attributes: (1) model variables are passed via subroutine argument lists rather than by common blocks and (2) model array space is dynamically allocated at run time. The reason for these attributes is to allow the same model code to calculate different nested grids for both the atmospheric and ocean models within a single program, and to avoid having to recompile the program for different simulations with different grids. To utilize the full capability for which COAMPS was designed, an ocean model being developed for use in COAMPS needs to be structured to be consistent with the COAMPS code architecture. Most existing ocean model codes are not structured in this way.

It was desired to include some additional capabilities in NCOM that are not currently available in POM. These include an explicit source term to simplify inclusion of river and runoff inflows, options for forcing by the local tidal potential and the surface atmospheric pressure gradient, and the choice of either the Mellor-Yamada Level 2.5 turbulence closure scheme as used in POM or the simpler and more efficient Mellor-Yamada Level 2 scheme.

Some additional features planned for NCOM that have not yet been developed include providing options for truncating (shaving) of the bottom grid cell on the z-level part of the grid to the bathymetry, for using an advection scheme that upwinds at fronts to reduce noise caused by numerical overshooting of the advection terms, and for flooding and drying..

Because of the increasing use of multi-processor computers by Navy operational and research and development centers, NCOM is being made to be scalable on commonly used multi-processor computers. Alan Wallcraft of NRL, who has a lot of experience with scalable model design, is assisting in this effort. Alan’s work on NCOM is funded by the Common High Performance Computing Software Support Initiative (CHSSI).

NCOM is being validated by testing its ability to correctly simulate basic physical processes and by comparing model simulations in some real environments with observations. Coupling between NCOM and the COAMPS atmospheric model is being tested in the Mediterranean. Several personel from NRL Monterey are participating in the coupled modeling effort including Richard Hodur, Xaiodong Hong, and Jian-Wen Bao.

WORK COMPLETED

A Fortran code for NCOM has been developed that is fully consistent with the COAMPS code architecture, i.e., that includes dynamic allocation of array space, passes all model variables through subroutine argument lists, and provides for an arbitrary number of levels of grid nesting. The nesting routines currently allow one-way nesting with an arbitrary number of nests. A basic description of NCOM is provided in Martin (1999).

NCOM has been made fully scalable, except for the nesting procedure. The scalability of the model was tested on the Origin 2000, the Cray T3E, and the IBM SP. Work was done to make all the model input and output data fully scalable, including initial conditions, surface forcing fields, open boundary data, river inflow data, and output fields. This work required the design of a procedure to handle open boundary and river data, which are input for specific points and must be allocated to the correct processor. The input data can be single fields that remain constant in time, climate fields that vary seasonally or monthly, or real-time fields that change at varying time intervals.

Several tests of NCOM were performed to verify its behavior. NCOM was tested for its ability to simulate some basic physical processes by repeating some of the tests conducted in the previous Coastal Model Comparison study with SZM, POM, and Alan Blumberg's Estuarine and Coastal Ocean Model, semi-implicit version (ECOM-si) (Martin et al., 1998). Tests that were run included advection, the formation of a tidal mixing front, and the propagation of barotropic shelf waves. The tests were conducted with sigma, with z-level, and with combined sigma/z-level vertical coordinates with the transition from sigma layers to z-levels set at different depths.

NCOM was compared with POM for a climatological simulation of the circulation in the North Pacific (POM was being run in the North Pacific in the NOMP Semi-Enclosed Seas Project).

NCOM was used to simulate the passage of Hurricane Eloise across the Gulf of Mexico in 1975, and results were compared with observations taken by a NOAA buoy.

The Mediterranean has been chosen as one of the areas to test the COAMPS coupled ocean-atmosphere modeling. For this work, NCOM was set up for the Mediterranean domain on several grids of differing horizontal resolution (5-, 9-, and 20-km). The coarser grids provide quicker turnaround for testing the simulation of the general circulation. The finer grids provide better representation of the smaller features in the Mediterranean, but, of course, take longer to run. Fairly fine grids are needed to simulate eddy features in the Mediterranean because of the small Rossby radius of deformation that results from the relatively weak stratification. At NRL-Stennis, the NCOM Mediterranean model is being driven by climatological forcing to see if it can reproduce the known features and transports in the Mediterranean. NRL-Monterey is forcing NCOM in the Mediterranean with real-time atmospheric fields from the European Center, from FNMWC, and from the COAMPS atmospheric model

RESULTS

The scalability of NCOM on multi-processor computers was tested on the Origin 2000, the Cray T3E, and the IBM SP. A 432 x 208 horizontal grid with 40 levels in the vertical was found to scale efficiently up to 16 processors. The same, basic NCOM code can be run on different computers by linking different message passing libraries developed by Alan Wallcraft.

Symmetry tests are frequently conducted with NCOM to check code changes. Normally, roundoff error asymmetries make it difficult to determine if small differences are due to actual coding errors or just to roundoff errors. However, NCOM has been made perfectly symmetric in its two horizontal dimensions by grouping terms to force symmetric calculations. As a result, NCOM gives perfectly symmetric solutions to symmetric problems, which is useful for testing and debugging and for certain modeling applications.

NCOM was compared with earlier tests of basic physical processes conducted with SZM. Since the numerics of NCOM are the same as the numerics of SZM, the results were expected to be the same, and the results were found to be basically the same. Changing the depth of the interface between the sigma and z-level grids for some of the tests that involved variable bathymetry gave the expected behavior.

NCOM was compared with POM for a simulation of the North Pacific. With the two models set up as similarly as possible, the results were very similar.

Results from NCOM for the simulation of the ocean's response to Hurricane Eloise in the Gulf of Mexico were compared with observations taken by a NOAA buoy located south of the Mississippi Delta in water of about 2000 m depth. The model results compared well with the buoy observations, but tended to under-predict the mixing with the default turbulence constants for the Mellor-Yamada Level 2 and Level 2.5 mixing submodels.

NCOM was used to simulate the Mediterranean with climatological atmospheric forcing as a preliminary step to testing with real-time atmospheric forcing from COAMPS. NCOM was able to reproduce many of the known circulation features in the Mediterranean including the Alboran gyres, the Algerian current, the cyclonic circulations in the Tyrrhenian and Adriatic Seas, and the gyres off SW and SE Crete. Some reported features have not been reproduced to date, however, this work is ongoing. Transports calculated through a number of passages including the Corsica Passage and the Straits of Sicily and Otranto are in fairly good agreement with observations.

IMPACT/APPLICATIONS

The ocean and the atmosphere are strongly coupled in coastal regions, and a combined ocean-atmosphere modeling system is frequently the optimal means of hindcasting and forecasting coastal areas. COAMPS is being developed by NRL to provide a high-resolution, coupled ocean-atmosphere prediction capability.

The payoff from this ocean model development project will be a functional and flexible model for ocean prediction that can be run by itself or can be run fully integrated with an atmospheric model within the COAMPS framework.

TRANSITIONS

As part of the COAMPS system, NCOM’s transition route into operations is through 6.4 SPAWAR funding for COAMPS. If NCOM is transitioned through this path, it will be run operationally at the forecast centers as part of COAMPS.

Within the NOMP COAMPS project, NCOM is currently being applied to the Mediterranean for testing with fields from the COAMPS atmospheric model, and current plans are to extend the coupled testing to other domains. This work is being done jointly by NRL Stennis and NRL Monterey.

In addition, NCOM is being used in a number of NRL Projects.

NCOM is being used by NRL's Coastal Remote Sensing (CoRS) Project to investigate the outflow plume from Chesapeake Bay. These simulations have been using singly and doubly nested grids with

horizontal resolutions as high as 200 m to look at the behavior of the outflow plume near the mouth of Chesapeake Bay caused by wind and tidal forcing.

NCOM has been transitioned to the NOMP 6.2 Semi-Enclosed Seas Project at NRL for simulations of the East Asian Seas. These simulations will use data assimilation and real-time atmospheric forcing to model the evolution of the northwest Pacific in real time.

A global version of NCOM has been transitioned to the NOMP Global Modeling Project at NRL. This model uses a curvilinear grid to cover the entire global ocean including the arctic.

NCOM will be used by NRL's CoBALT (Coupled Bio-physical-dynamics Across the Littoral Transition) Project to simulate the ocean off the U.S. west coast.

RELATED PROJECTS

NRL-Monterey is being funded by NOMP to assist in the development of NCOM and the installation of NCOM into COAMPS.

A joint project between NRL-Stennis and NRL-Monterey, entitled "Ocean Data Assimilation for COAMPS", is working to develop an ocean data assimilation system for COAMPS.

Dr. Alan Wallcraft of NRL, working under the CHSSI Program, has been helping to parallelize the NCOM code.

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